Risk Assessment of Deckings of Dangerous Goods Routes – A knowledge inventory

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ABSTRACT

This paper focus on challenges related to risk assessment and risk control when decking transport routes for dangerous goods with deckings. The objective is to carry out a knowledge inventory in international research literature on risk management and deckings, which also includes practice regarding different types of protection measures. This is done in combination with a current situation description of how this type of problem is handled in practice today. The review of literature is carried out with a so-called scoping study. It is expected to identify a number of possibilities for dealing with this type of risk management problem, as well as the evidence that may exist as support for different approaches. Interviews will be conducted with experts in the field who are active in Sweden. The interviews will partly be designed on the basis of the literature review and together these two methods will hopefully give a good picture of the current state of knowledge partly in the academic literature, but also in the practical context. In summary, we can state that there is some research concerning tunnels in general and the transport of dangerous goods, but when it comes to specific problems with deckings, there is a lack of studies. In some cases, the problem of deckings is mentioned, but there are no articles dealing with how this type of problem is solved in other countries, or about suggestions on how to manage risks in connection with deckings. From a risk governance perspective significant effort is necessary to facilitate sound and robust prerequisites to risk management of deckings to safe-guard that we are not drifting into failure and introduce risks in our modern society that we potentially will regret tomorrow.

KEYWORDS: decking, underpass, overbuild, dangerous goods, restrictions, ADR, RID, risk analysis

INTRODUCTION

This paper will report on results from the research project "Risk assessment and risk control when decking transport routes for dangerous goods" which is carried out by the Division of Risk Management and Societal Safety, Lund University, and Brandskyddslaget AB on behalf of the Swedish Transport Administration during 2022.

Background

Projects to cover, deck or overbuild transportation routes are becoming increasingly common, sometimes creating an underpass under populated areas where transportation of dangerous good potentially can occur. However, there is considerable uncertainty with respect to how risk should be dealt with in this type of project. This is primarily related to risks associated with the transportation of dangerous goods.

One the one hand, there is an ambition to allow as much flexibility in terms of the usage of the piece of land above or in direct vicinity of the decking. On the other hand, there is also a desire to not impose too much restrictions in terms of what kind, and how much, dangerous goods can be transported on the route. These two overarching goals can end up in conflict with each other. For

example, if a building with high occupant load is built on top of the decking, restrictions in terms of transportation of dangerous goods might have to be imposed and/or restrictions in terms of the use/design of the building.

The fear of exploitation above deckings is that accidents involving the transport of explosives (ADR / RID class 1) and oxidizing substances and organic peroxides (ADR / RID class 5) can cause accident scenarios that result in damage to a large number of people, and buildings, above and adjacent to the canopy. In a dense metropolitan environment, there may be very many people who could potentially be exposed to negative consequences from this type of accident scenario. The damage can be considered unproportionally large.

Regarding this type of potentially catastrophic scenario, there are no overall safety targets or acceptance criteria regarding risk in Sweden that can be directly applied to deckings. There are no accepted principles for risk assessment of this type of risk, in addition to a general statement that it is desirable to try to avoid disasters. This means that it is unclear what constitutes the basis for assessment, e.g. when assessing whether it is safe enough to build above a cover of a transport route for dangerous goods. Such assessments are necessary to answer questions such as: "Is it appropriate to build on top of a decking?" or "Are more risk mitigation measures required for this to be appropriate land use and a good built environment?" or "Does the proposed land use above the decking entail any restrictions on what is allowed to be transported on the road and rail network?". There is therefore a need for increased knowledge about how this type of project should be handled from a risk perspective.

The present paper is a result of a research project aimed at contributing with knowledge about the problem of managing risk in this type of context and contribute to a more appropriate management in practice. The project was focused on the Swedish context, but it is likely that similar problems are encountered in other countries as well. To increase our knowledge on how these types of potential conflicts between exploitation (of the area above the decking) and transportation (of dangerous goods below the decking) are dealt with and suggest ways to improve practice, two methods were used. First, a review of international scientific papers focused on risk management and deckings were carried out to determine what is known about the management of risks with respects to transportation of dangerous goods and deckings. Secondly, an interview study was conducted focusing on Swedish professionals involved in decking projects with the aim of describing current practice and identify challenges and opportunities for development.

The paper is organised as follows. First the literature review is presented, and its results are briefly discussed. Then the interview study is presented, and the results are discussed considering the literature review. Finally, we offer some suggestions on what might be done to improve the management of risk with respect to transportation of dangerous goods in decking-projects in Sweden and elsewhere.

METHODS

Literature study

To carry out the review of knowledge in international scientific journals, a so-called Scoping study was used. There are several different ways that you can use to systematically search scientific literature for relevant knowledge. There are several reasons why we chose this method.

First, we do not expect the knowledge sought to necessarily be found within the framework of a specific research area, or in one or a limited number of scientific journals. The reason for this is that the problem of managing risk with regard to dangerous goods in connection with the decking of transport routes is multifaceted and thus there are several different perspectives that can be taken to

study it. For example, one could focus on the construction aspects of the problem and investigate the impact of blast load on various building elements that occur in decking constructions. Another example is that one could focus on the decision situation, for example how to make (or should make) balances between different goals, in connection with this type of project. There are thus several different types of studies that could potentially be of interest within the framework of this project and we have no reason to believe that these are limited to a research area or in a limited number of journals. Scoping studies are suitable in such contexts (see for example [1]) because they provide the opportunity to search widely in the scientific literature, but at the same time offer a methodology that makes it possible to filter and focus on the material that is of interest in the project. An alternative approach could have been a so-called systematic review [2]. However, such an approach presupposes a well-defined problem and research question(s). And what is common with this type of study is that you want to study the effects of interventions by combining results from several studies that are based on quantitative methodology. Roughly, one can say that a systematic review would have been appropriate if we knew where (which journals) we could expect to find it and if the methods used were similar (and quantitative).

Another alternative to applying a scoping study would have been to carry out the literature review in a less systematic way. After all, scoping studies require a rather large effort (see below) and it is not always certain that such an effort is justified. However, our assessment is that we could not satisfactorily achieve the first goal without conducting a comprehensive and systematic review of the literature. This is because the problem of managing risk associated with the transport of dangerous goods is multidisciplinary, meaning that it has been tackled in several different scientific disciplines. For example, one can imagine that the impact of explosions on a decking has been discussed in scientific journals with a focus on construction technology. Furthermore, the question of disaster risk, i.e. risk associated with potential events that can cause a great deal of damage, can be dealt with in journals that have just such a focus.

We have followed the general method description for scoping studies as described in [3] [4] [5]. There are minor variations in how such studies are conducted, but there is nothing affecting in this context. The methodological steps that are usually included in a scoping study are the following (based on [3]):

1. Formulate a research question
2. Develop relevant keywords and search strategies
3. Filter and select relevant studies
4. Describe the results
5. Summarize and report

We have followed these steps, but we have also added more analysis of what we find in our searches than is normally associated with a scoping study. And we have also added a citation analysis under point 3 which is not normally found in this type of study (see description below).

Formulate a research question
The literature study aims to provide answers to two questions (see the previous chapter) which deal with covers and dangerous goods. We could have used these as a starting point for the scoping study, but the risk is that the question is too narrow and that we then miss literature that is relevant to the study, but which does not specifically address the issue of coverage. Therefore, we have started from the broader question: “What knowledge about risk management with regard to the transport of dangerous substances in tunnels or under covers is described in the scientific literature?”

Develop relevant keywords and search strategies
In order to answer the research question, one must find a number of keywords that adequately reflect it. The keywords are then used to conduct searches in various databases that contain scientific articles. We have chosen to apply a strategy that involves searches in all scientific journals that are included in the Scopus database. It contains over 30,000 scientific journals and is one of the most comprehensive databases of scientific articles.

When designing a search strategy, a balance must be made between how much work can be put into the search itself and the risk of missing relevant articles. We have chosen to limit our searches to articles published in scientific journals after 2010 until March 2022. This means that neither publications in scientific conferences, nor those published in 2010 or earlier are included in our search. Our assessment is that this delimitation is reasonable given that we are interested in the current knowledge front. In addition, we include a citation analysis in our search strategy, which means that we can also capture older relevant publications (see below). Another limitation that we have chosen to implement in order to avoid an excessive amount of hits during the searches is to exclude scientific journals in areas that we do not consider relevant in this context. Based on the research question above, use the following keywords in the searches: "risk management", "risk assessment", "risk governance" and "risk analysis".

We first tried just using the term "risk", but that generated too many hits to be useful. Next, we tried different variations of keywords to see which generated a manageable number of articles in the results and also seemed to result in relevant ones. The four concepts above are used in slightly different contexts. Together they seem to capture a wide range of articles that are variously relevant here. For example, the keyword "risk analysis" gives hits on articles that often deal with methods for assessing risk, while "risk governance" gives hits that are more focused on managing risk in complex contexts with several actors involved. However, these risk keywords are too broad to provide meaningful results in this project. You need to make further delineations in order to find articles that are of interest from an overlap/dangerous goods perspective.

It is not easy to find suitable such keywords. For example, we have included words such as "capping" and "decking" (see below), but these in combination with the risk keywords do not yield as many hits. Therefore, we have also chosen to include keywords that are significantly broader, for example "urban". We have chosen these keywords by testing searches with them, in combination with the risk keywords, and analyzing the hits we have received. If we received many relevant hits, we have chosen to use the keyword. The final list of keywords that we combined with the risk keywords are: "infrastruct*" "transport*" "urban", “capping*” “decking*” “overbuilding*”, “underpass*”. Using "*" in a search means covering several different specific keywords. For example, "infrastruct*" means that both "infrastructure" and "infrastructures" are covered.

In addition to combining the keywords dealing with risk with those associated with the transport/construction itself, searches were also carried out with the keyword "tunnel" in combination with either "hazardous material" or "dangerous goods". In total, this gave rise to 18 different searches in Scopus. The searches, as well as the number of hits they resulted in, are illustrated in the figure below. The searches take place in the titles and abstracts of the scientific journals. In order to generate a hit in a search, at least one risk keyword and at least one of the other keywords must be found in either the title or abstract.

In total, the 18 searches thus resulted in 27254 hits, i.e. articles that meet the conditions in any of the searches. However, these hits contain some duplicates because the same article can meet the conditions in more than one search. After duplicates were sorted out, 21155 articles remained.

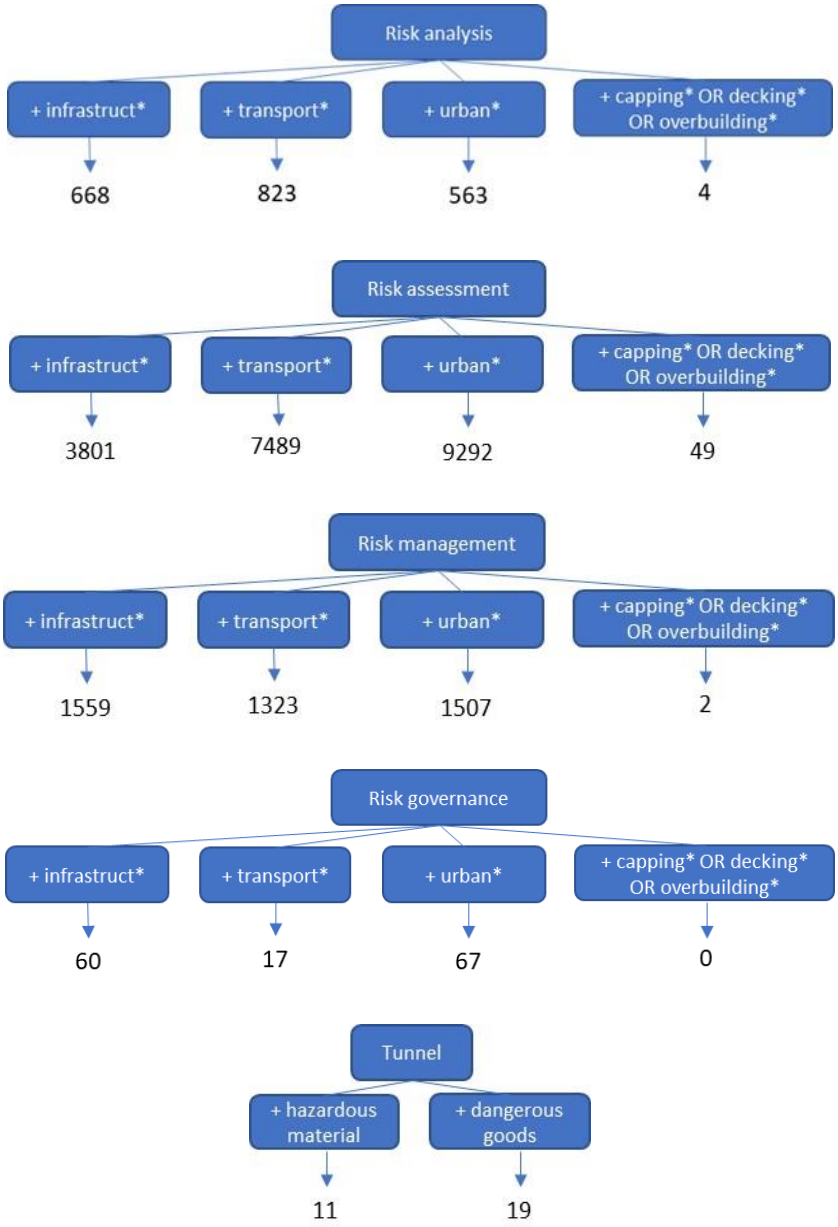

Figure 1. Description of the various searches and their results. The searches mean that the word at the top (e.g. "risk analysis" or "risk assessment") must be in the title, abstract or keywords for a scientific article to be included in the search results. In addition, one of the keywords found under these words must also be included in these search fields.

Filter and select relevant studies

Such a large number of articles cannot, for obvious reasons, be reviewed in detail. And it is also not desirable because most of these are probably not relevant to this study. Instead, the scoping study methodology means that you have to filter the results in different ways to reduce the number of articles to a manageable number. Filtering thus means removing articles that you judge not to be of interest.

Filtering Step 1: Filtering based on journals

The first filtering step that we applied in this study is based on identifying journals that are not judged to be relevant to the question. An example of such a journal is the "International Journal of Pediatric Otorhinolaryngology". In that case, it is clear that the articles included in the results from our search

and published in that journal are not relevant. The focus of the journal is surgery concerning the neck and head for babies and children. The reason why we still found articles in that journal that meet our criteria may be that they write about risk assessments in healthcare and that the article may be about some type of new "infrastructure" to do this. There are several thousand irrelevant journals in our material. By reviewing all journal titles in our material and deciding whether it is relevant in the context, we were able to remove 3253 journals. In this review, we were supported by an algorithm that identified potentially irrelevant journals based on the number of articles identified in the journal. If only single articles are included in our results from a specific journal, it is a good indication that the focus of the journal is probably not relevant within this study. After the articles from these journals were filtered out, 5322 articles remained that were published in 140 different journals.

Filtering Step 2: Filtering based on titles
The next step in the filtering process involved a review of the articles' titles. The goal was to identify articles that are with a high degree of certainty not of interest in the study. Articles that are not specifically about covers and dangerous goods, but which we judge could still be of interest, are not filtered out. This could, for example, be about titles that indicate that an article is about tunnel safety. Examples of articles removed in this step are those where the titles indicate that they are about cyber security[1], flood risks[2], risk management in critical infrastructures such as electricity distribution systems [3], etc.

Both authors reviewed all 5322 titles. In order for a specific article to be filtered out, it was required that both authors assessed the article as uninteresting for this study. If only one made such a judgment, the specific article was not removed. The result was that 5124 articles could be filtered out and thus only 198 articles remained after this filtering step. In 97.3% of the cases, the authors made the same assessment of whether a specific article is of interest to the study.

Filtering Step 3: Filtering based on abstract
The final filtering step to identify relevant studies involved reviewing the abstract for each of the 198 articles and determining whether a specific article could be removed from the study. In addition, in connection with this review, a classification of the articles that were not removed was carried out. The classification meant that the remaining articles were divided into two groups, group 1 and 2. The articles that ended up in group 1 were judged to be of greatest interest to the current study, and those that ended up in group 2 were judged to touch on aspects that could possibly be of interest. The result after this filtering step was that 13 articles ended up in group 1 and 41 ended up in group 2. Figure 2 illustrates the entire filtering process from start to finish.

The figure also illustrates the result of a citation analysis that was carried out based on the 13 articles that ended up in group 1. The analysis means that all articles that refer to any of the 13 in group 1 were identified via a search in Scopus. The result was 207 articles. The idea of this analysis is to capture any articles that may be relevant to the study, but which for some reason we did not find through the procedure described above. Since the 13 articles in group 1 are those judged to be most relevant to this study, it is reasonable that other articles that refer to them could also be of interest. The result of this analysis, however, meant no further additions to group 1, but instead 1 article was judged to be relevant enough to end up in group 2. This brings the total number of articles in that group to 42. In addition to these 42, we are also aware of 4 articles that were not included in the scoping study. This is because they were published earlier than 2010 or are published in journals that are not included in Scopus. The four articles are included as the last 4 in the final analysis presented in the next chapter (see Table 2).

1 One example is the title “Stochastic Counterfactual Risk Analysis for the Vulnerability Assessment of Cyber-Physical Attacks on Electricity Distribution Infrastructure Networks”.
2 One example is the title “A Probabilistic Model of the Economic Risk to Britain's Railway Network from Bridge Scour During Floods”.
3 One example is the title ”Risk reduction methods for managing the development of regional electric power industry”.

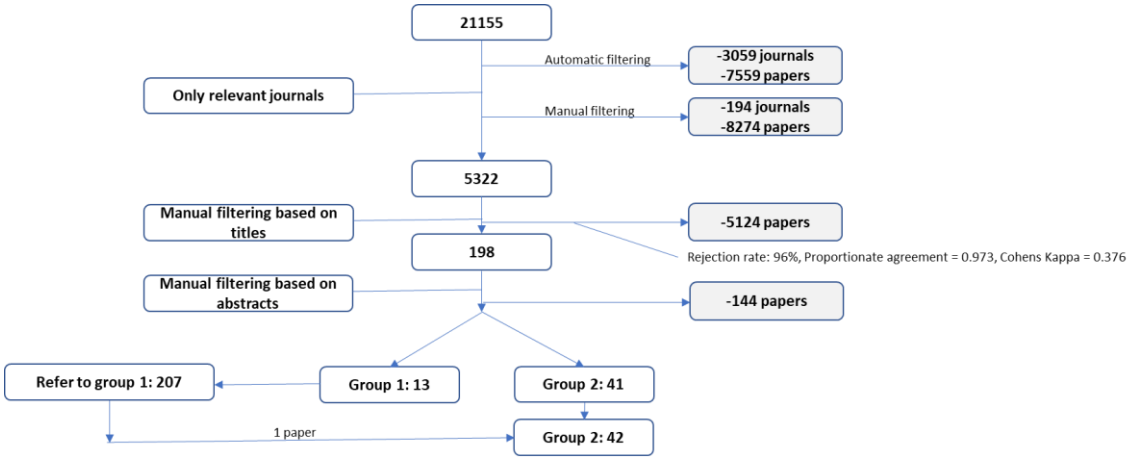

Figure 2. Description of the filtering process.

Many of the articles in groups 1 and 2 are published in journals that are well known in risk research (Safety Science, Risk Analysis and Reliability Engineering and Systems Safety). In addition to these, several articles have been published in journals with a focus on sustainability research (Sustainability and Sustainable and Resilient Infrastructure). In addition, there are some publications in journals focused on transport research (e.g. Transportation research and Transport policy). See Figure 3 for an overview of all journals and the number of articles published in them.

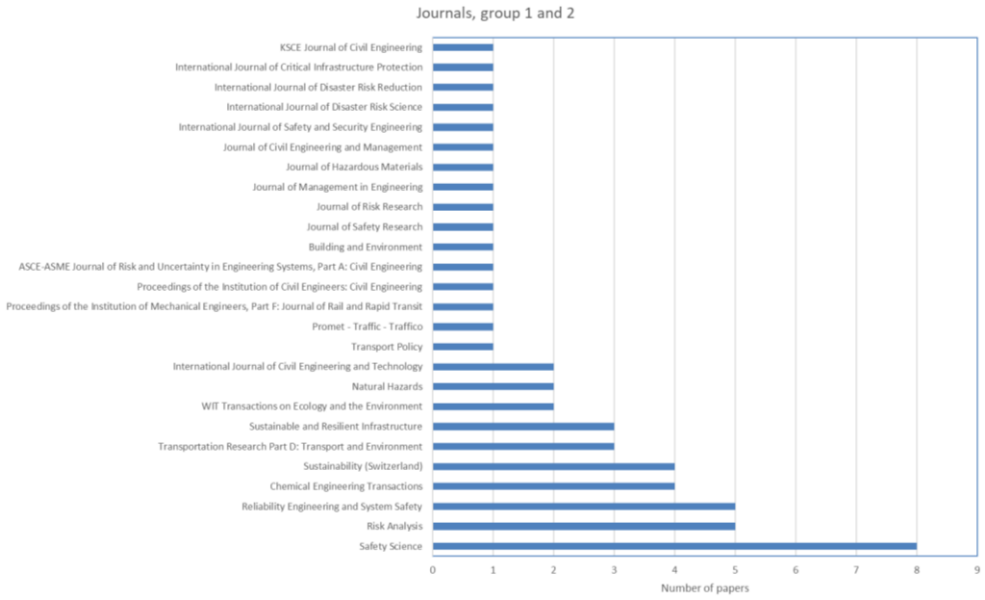

Figure 3. The number of articles in groups 1 and 2 that are published in various scientific journals.

Regarding articles included in group 1, almost half of the articles are found in Safety Science or Sustainable and Resilient Infrastructure, see Figure 4.

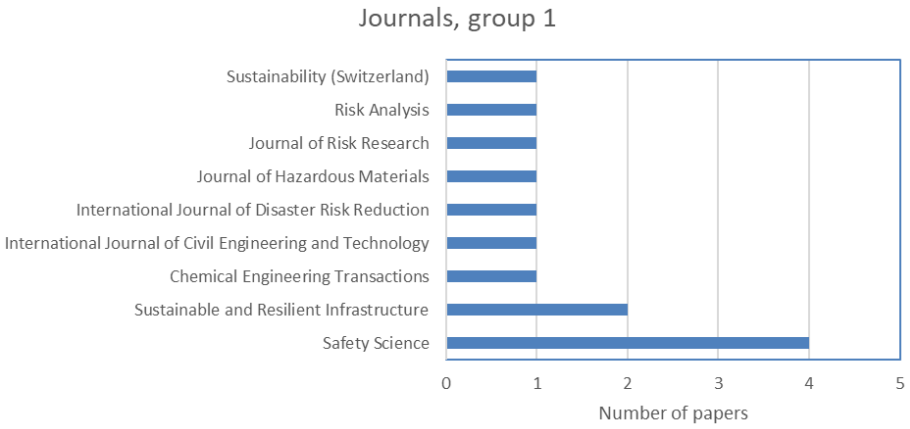

Figure 4. An account of how many articles in group 1 are published in various scientific journals.

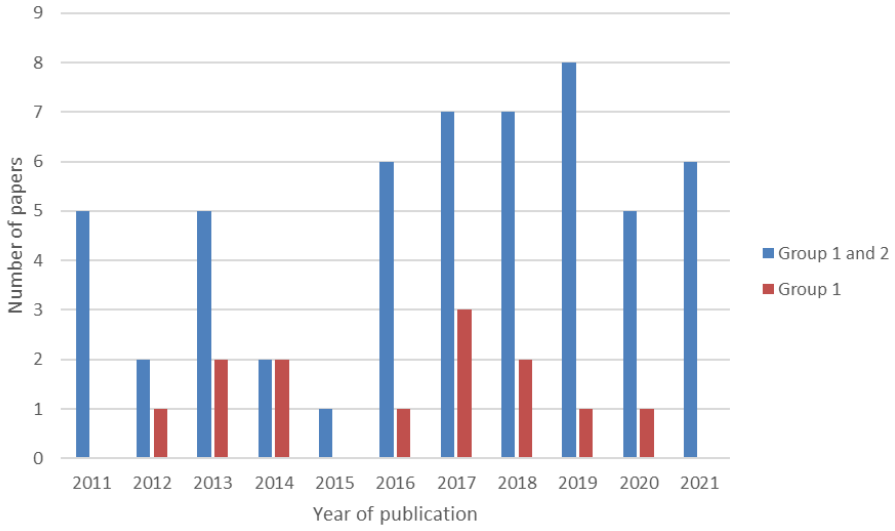

Figure 5. Illustration of the number of published articles per year that are part of groups 1 and 2. Blue bars show the number of articles from both groups. Red bars show group 1 only.

Overall, the figures above indicate that the type of research that is of interest within the scope of this report appears to be spread across several different research fields. Roughly speaking, the fields can be called Risk/safety research, Transport research and Sustainability research. The most relevant research seems to be concentrated in the journals that are normally associated with traditional risk/safety research, but there are also some such contributions in journals that are more about sustainable development research. Furthermore, it appears that interest in this type of research has been relatively constant, at a low level, over the past ten years. By "low level" we mean the fact that we find fewer than ten articles per year that have to make them the type of problem of interest. The number of articles is even lower if you consider those that are of high interest. Such a limited amount of articles is considered "low" considering the very large amount of research articles published each year in any of the three areas above.

Interviews

To supplement the input on how risk is managed in connection with deckings and dangerous goods that we can get from the scientific literature, an interview study is also included that can provide better insight into how this type of problem is handled in practice in Sweden. The purpose of the interview study is thus to supplement the literature study in order to be able to give a more comprehensive answer to questions 1 and 2 (see chapter 2).

It is important to note the limitations of the interview study right from the start. It is not intended to give a representative picture of what different people working with the current problem think or do. Such a study must be much more comprehensive than the one included in this project. Instead, the interviews are used to gain insight into how risk is managed today, as well as to gain knowledge about problems and opportunities. In order to best achieve the purpose of the project, the people interviewed have been selected to get as wide a spread as possible in terms of which different actors (Traffic Agency, municipality, county board, etc.) the people represent. In addition, the focus has been on contacting people who we judge to have very good knowledge of the current type of problem. A total of 10 interviews have been conducted with 11 people. The turnout among the respondents was good. Only a few declined. Table 1shows which organizations those interviewed in the project work within.

Table 1. List of organizations that the interviewees work within.

Interview	Stakeholder
1	The Swedish Transport Administration
2	The Swedish Transport Administration
3	The Fire and Rescue Service in Stockholm
4	The Fire and Rescue Service in Stockholm
5	The City of Stockholm
6	Jernhusen[4]
7	The National Board of Housing, Building and Planning in Sweden
8	The Swedish Transport Agency
9	The Swedish Civil Contingencies Agency
10	The County Administrative Board of Halland (2 persons)

The interviews were carried out during the period 2 June to 21 October 2022 and they were carried out partly on site (4 interviews) and remotely (6 interviews). Both authors were present at all interviews. One was responsible for taking notes and one was responsible for managing the interview. The interviews were conducted as semi-structured interviews, which means that there was an interview guide as support for the interviews, but that deviations from this were accepted if it was judged to be in the interests of the project. The interview guide was developed in the spring of 2022 and is structured in three parts. The opening part is about the person being interviewed being able to tell about their own role in working with deckings, the middle part is about the current situation, i.e. how risk is managed in decking projects today, and the concluding part focuses on how management can be improved in the future. The interview guide shows which questions were asked can be found in the project report soon to be published.

RESULTS AND ANALYSIS

Scoping study

In Table 2 there is information on the 13 articles which, based on analysis of titles and abstracts, were judged to be very relevant to the project based on the scoping study and the additional 4 identified in addition. In the text below, we use square brackets and the numbering on the far left of the table when we refer to them. For example, [a] means a reference to the first article, [b] to the second, and so on.

An overwhelming majority of the reviewed articles have a geographical focus on Europe [a, b, c, e, f, g, h, i, n, o, p, q], followed by North America [d, j, m]. Others have a more general global focus [k]. Most have a focus on road transport [a, e, g, h, i, l, q], others on rail [c, d, f]. Other articles do not deal with any specific type of transport.

The articles that focus on Europe in most cases address and relate the research to EU Directive 2004/54/EC [6] [a, e, g, h, I, q], while others only concern the Dutch legislation [c, f]. Only one of the

4 Jernhusen is a publicly owned real estate company with properties related to the Swedish railroad system and railway infrastructure.

articles with a European focus lacks a clear connection to legislation in the area [b, n, o, p]. None of the articles with an overseas focus concern legislation to any great extent.

Table 2. The 13 + 4 articles belonging to group 1, i.e. those that, based on the title and abstract, have been judged to be highly relevant to the current project.

	Year	Author	Title	Journal
a	2012	Kazaras, K., Kirytopoulos, K., Rentizelas, A.	Introducing the STAMP method in road tunnel safety assessment	Safety Science
b	2013	Renn, O., Klinke, A.	A framework of adaptive risk governance for urban planning	Sustainability
c	2013	van der Vlies, V., van der Heijden, R.	Urban planning and rail transport risks: Coping with deadlocks in Dutch urban development projects	Safety Science
d	2014	Liu, X., Saat, M.R., Barkan, C.P.L.	Probability analysis of multiple-tank-car release incidents in railway hazardous materials transportation	Journal of Hazardous Materials
e	2014	Kazaras, K., Kirytopoulos, K.	Challenges for current quantitative risk assessment (QRA) models to describe explicitly the road tunnel safety level	Journal of Risk Research
f	2016	Houdijk, R.M.	Rail transport of hazardous substances from the perspective of 'All Hazard' Risk Management	Chemical Engineering Transactions
g	2017	Caliendo, C., De Guglielmo, M.L.	Simplified method for risk evaluation in unidirectional road tunnels related to dangerous goods vehicles	International Journal of Civil Engineering and Technology
h	2017	Benekos, I., Diamantidis, D.	On risk assessment and risk acceptance of dangerous goods transportation through road tunnels in Greece	Safety Science
i	2017	Caliendo, C., De Guglielmo, M.L.	Quantitative Risk Analysis on the Transport of Dangerous Goods Through a Bi-Directional Road Tunnel	Risk Analysis
j	2018	Salem, S., Campidelli, M., El-Dakhakhni, W.W., Tait, M.J.	Resilience-based design of urban centres: application to blast risk assessment	Sustainable and Resilient Infrastructure
k	2018	Borsekova, K., Nijkamp, P., Guevara, P.	Urban resilience patterns after an external shock: An exploratory study	International Journal of Disaster Risk Reduction
l	2019	Lundin, J., Antonsson, L.	Road tunnel restrictions – Guidance and methods for categorizing road tunnels according to dangerous goods regulations (ADR)	Safety Science
m	2020	Stewart, M.G., Mueller, J.	Terrorism risks, chasing ghosts and infrastructure resilience	Sustainable and Resilient Infrastructure
n	2005	Suddle, S. och Ale, B.	The third spatial dimension risk approach for individual risk and group risk in multiple use of space	Journal of Hazardous Material
o	2009	Suddle, S.	The risk management of third parties during construction in multifunctional urban locations	Risk Analysis
p	2009	Suddle, S.	The weighted risk analysis	Safety Science
q	2018	Lundin, J.	Risk Evaluation and Risk Control in Road Overbuilding of Transport Routes for Dangerous Goods	Journal of Civil Engineering and Architecture

Risk analysis methods

In our material there are some articles that explicitly deal with deckings and risk analysis [n, o, p]. Suddle and Ale introduce a risk analysis method that they call third-dimensional risk analysis and show how it can be applied to roofing in the Netherlands [n]. This method is then used by Suddle when he shows how it can be used to analyze risk with regard to falling objects during the construction period (it is then assumed that the traffic is allowed on the traffic route during the overlay) [o], and also how it can be developed into to become a type of cost/benefit analysis [p].

Several articles deal with methods for carrying out risk analyses/risk assessments. The so-called DG-QRAM method (Dangerous Goods – Quantitative Risk Assessment Model) often appears in the reviewed articles[5]. It can, for example, be about showing its application in a specific case [i], where that method is one of several being tested [h], or where DG-QRAM is used as a reference to develop simplified risk assessment models [g]. DG-QRAM appears to be a commonly used method for risk analysis with respect to tunnels. However, it makes no difference whether the tunnel in question is overbuilt or not. Another method that is also based on quantitative risk analysis (QRA) is presented in [f]. That method has been developed within the EU-funded projects MiSRaR and PRISMA. There, the Dutch method for analyzing SEVESO facilities and the transport of dangerous goods to and from them has been compared with the method used in the Netherlands to carry out so-called "all hazards

5 This method was developed by the organizations PIARC and OECD and is used today in 26 countries (see DG QRAM Webinar – 23/06/21). There is software that can be used to carry out risk assessment using the method.

risk assessments". These analyzes have their background in the Sendai framework[6] which, among other things, means that countries carry out analyzes of disaster risks at national level. In Sweden, these are carried out by the Swedish Civil Contingencies Agency (MSB) and are part of what is called the National Risk and Capability Assessment [7]. The method proposed in [f] involves a combination of the two methodologies with application to urban planning.

Another example of a risk analysis method focuses on rail transport [d]. However, that method is limited to assessing the likelihood of different types of derailment scenarios. It does not contain any support for impact assessment (given that a derailment has occurred), nor does it have support for presenting and assessing risk. In another article, the Systems-Theoretic Accident Model and Processes (STAMP) method is applied with regard to tunnels and risks [a]. STAMP is a relatively new type of method developed to deal with some of the weaknesses associated with traditional quantitative risk analysis methods. There are also examples of work where several different quantitative variants of risk analysis methods for tunnels are compared. Reference [e] is an example where the Austrian method TuRisMo, the Dutch TUNPRIM RWS-QRA, DG-QRAM, and QRAFT are compared. However, the article does not contain much detail regarding the various methods and overlaps are not given space in the analysis. However, it presents an analysis of weaknesses that apply to all the methods discussed in the article. Some of these may also be relevant in relation to coverages for the management of risk in respect of dangerous goods. Especially those that deal with weaknesses in handling uncertainty and the systems' complexity and development over time.

Problems/Difficulties/Solutions

The articles reviewed contain several accounts of problems and difficulties with regard to risk management in the current context. Some of the articles have a strong focus on explosions and in these [j, m] they discuss, for example, the difficulties of weighing the costs of protecting various buildings against explosions against the benefits that protection provides should an explosion occur. Particular emphasis is also placed on the fact that current legislation (in North America) is based on individual components when analyzing the impact of buildings on explosions rather than considering several components as a cohesive system. It is proposed [j] a development that involves the use of PRA (Probabilistic Risk Assessment) to analyze explosion risk from a system perspective, i.e. where you consider the building construction as a whole and not just focus on individual components. In addition, a more resilience-inspired approach is advocated, where the focus is on the impact of an explosion on the societal function maintained by the building in question. Loss of functionality and recovery time are important to consider from this point of view. This is a big difference to how safety in tunnels is usually analysed, at least according to the analysis methods described above, where the focus seems to be on life safety and not the functionality of the tunnel/overbuilding. Also [m] touches on an interesting difficulty with analyzes of primarily explosion risk as a result of antagonistic attacks. It is noted that in this type of analysis, the person analyzing the risk often tends to focus on worst-case scenarios and thus overestimate the risk. The article contains a review of previous terrorist attacks with powerful bombs. They focus on infrastructure and are therefore only interested in larger charges that can cause extensive damage to buildings, bridges, tunnels, etc. After their analysis of the problem, they conclude that terrorists (in a Western context) rarely succeed in causing extensive damage to various infrastructures and that many of the robustness-enhancing measures that have been taken in the US in particular are not cost-effective, given that a terrorist attack is very unlikely and if one does occur, it is very unlikely that it will succeed in causing extensive damage.

In [b], problems and difficulties with regard to risk management that can arise in connection with urban planning are described. The article is not about deckings or other tunnel types. Despite that, the material may be of interest here because it deals with general risk management situations in connection with urban planning and describes some of the difficulties that can arise where there are many different actors involved in the management and where the situation is characterized by great

6 Sendai Framework for Disaster Risk Reduction, UN (2015).

7 See, for example, the report”Kraftsamling – för en stärkt civil beredskap” av MSB, 2021.

uncertainties, complexity and ambiguity. One also presents a type of solution for how risk management problems should be handled. It is based on a risk governance model developed by the IRGC (International Risk Governance Council) and the article describes how it could be applied with regard to community planning. However, the model is relatively abstract and does not provide much concrete guidance. In addition, the authors point out that the model is still untested in practice.

In [f] several problems are highlighted with the quantitative risk analysis methodology used in the Netherlands, both for the analysis of dangerous goods risks in tunnels and at SEVESO facilities. It concerns, for example, that the results from such an analysis can vary greatly based on which assumptions are made. This in itself is not so strange because all risk analyses mean that you have to make assumptions. But in the Netherlands, the method you have to use is strictly regulated by law and the analyses themselves carry a lot of weight when it comes to decisions regarding risk issues. Therefore, it is particularly serious that despite a well-specified method for the same system, e.g. the same tunnel, can have very different results depending on which assumptions you make. It should also be noted that all these assumptions can be seen as reasonable and acceptable under the current legislation. They also touch on the problem that they often only focus on the protection of life and health in this type of analysis and not on the functionality of society. Another article that highlights problems common methods for analysing risk in tunnels (eg DG-QRAM, TuRisMo, etc.) are associated with is [e] and to some extent [a]. [e] focuses on several different aspects that are inadequately handled in the current methods of risk analysis, for example human behaviour, system complexity, the dynamic nature of risk, etc. One aspect that the authors are particularly critical of is how uncertainties are analysed and described in the analysis models. They suggest, for example, that existing quantitative risk analysis methods used in the field of tunnel safety be supplemented with clear descriptions of the so-called knowledge base, which for example includes accounts of assessments and assumptions made in analyzes (see, for example, [6]).

Article [c] differs somewhat from the other articles in terms of problems and solutions addressed. That article focuses on the institutional problems that arise in relation to the management of risk in relation to the transport of dangerous goods in connection with the planning and construction of railways (in the Netherlands). It identifies six categories of problems and suggests how the effects of these problems could be mitigated through a change in the decision-making processes surrounding the construction of new railways in the Netherlands. Also [l] addresses problems that are not so much about how to analyse risk in tunnels, but about how to decide which category (A to E) a tunnel should be classified as. The categories govern which restrictions with regard to the transport of dangerous goods must be applied in the tunnel. It also mentions that dangerous goods that cannot be transported through a tunnel must travel on an alternative route, which means that you expose others (not those staying in the tunnel) to risk. Analysing risk with regard to such an alternative route is very important to have something to compare with a possible tunnel transport. This problem is also discussed in [i].

Interviews

We do not reproduce individual interviews in the results section, but only summarize them by presenting several themes that have been touched upon. If there are aspects that have only come to light in individual interviews, this is evident from the text. When we describe the themes, we have chosen to also relate them to the literature study and to other knowledge in the area of risk management.

The big problem is disaster scenarios

If you combine what we have seen in the literature study with what emerged during the interviews, it is clear that the difficulties in managing risk in connection with the design of deckings with a focus on the transport of dangerous goods are above all about disaster scenarios with cargo that, under unfortunate circumstances, can lead to detonation (eg ADR/RID class 1 and 5). These are scenarios that could potentially lead to a very large (thousands) number of dead/injured people. There are of course also challenges with risk management regarding other types of scenarios, for example a serious fire in a tunnel under a decking, but this type of scenario is usually handled in the methods used today in Sweden and elsewhere. This is also the case with the methods that we came into contact with

within the framework of the literature study, for example the so-called DGQRAM method. What can be noted is that disaster scenarios, for example an explosion in a transport with more explosive goods than what the tunnel construction was designed to withstand, are not explicitly included in these methods. This is problematic.

How this type of disaster risk should be valued is not clear in the studied literature, and from the interviews we get the impression that in practice there is no accepted way of handling this type of risk either. Admittedly, proposals for handling such risks in projects have had to be drawn up (e.g. for the decking of the central station in Stockholm), but then a lot of work has been put into coming up with suitable working methods to manage the risk in that particular project. However, whether these methods can/should also be used in other places and in other projects is unclear, which leads us to the next theme.

Lack of guidance
As pointed out above, there are several different risk analysis methods for analyzing and evaluating risk in connection with dangerous goods in tunnels. However, when it comes to the most serious scenarios that can occur, there is a lack of accepted methods to evaluate these, which creates difficulties for various actors and stakeholders. Regardless of whether it is a municipality that must approve a detailed plan, or whether it is a county administrative board that must make a decision to review or re-examine such a plan, or a designer that develops proposals for risk-reducing measures, the lack of guidance leads to problems. Above all, because it creates great uncertainty among the actors involved.

It is important to be clear that there are different types of uncertainty in these contexts. Firstly, there is uncertainty regarding the overlay itself, i.e. whether there will be an explosion, for example, or not there, and if so, what the consequences will be. This uncertainty is normally handled in different types of risk analyses. However, the lack of guidance also creates another type of uncertainty that is not directly related to the facility itself. It is rather about uncertainty regarding what the actions of the actors, for example a certain decision, will entail. In the end, this uncertainty contributes to something that can be described as "project risk" for the various actors, i.e. the possibility of suffering negative consequences due to activities within the decking project and not due to, for example, a dangerous goods accident.

In this context, project risk can mean that an actor, for example the Swedish Transport Administration, a municipality or a developer, risks being affected by delays and increases in costs in a decking project. And, the lack of guidance means that the uncertainty about whether such consequences may arise is greater than it would have been if there had been better guidance on how (catastrophic) risk in relation to the transport of dangerous goods would be managed. But project risk in this context does not only have to be about potential financial costs in the specific project, it can also be about the possibility that an actor makes a decision that is subsequently criticized and perhaps even turns out to be incorrect. Because guidance is perceived to be lacking, or at least deficient, there is always some possibility that a decision that has been made may turn out to be wrong in retrospect. Even if one disregards possible financial consequences, there still remains a risk for the stakeholders, even for individuals, for example administrators, to make decisions that later appear to be incorrect, or otherwise very bad.

This type of project risk is of course always present, but in most cases it is less extensive because there are well-developed methods, procedures and reference examples (practice) for how to handle different types of safety problems, for example life safety in tunnels. What makes deckings special from this perspective is that the uncertainty for the actors involved becomes greater.

Finally, there is another aspect which is important in this context and which is related to the lack of guidance. We call it precedent risk. As there is relatively little guidance regarding how disaster risk with regard to the transport of dangerous goods should be handled, each completed project means that the handling applied there becomes a precedent that can then be used in subsequent projects. This is

usually something positive because it is a type of learning, i.e. experiences from previous projects are used in subsequent ones. But, in this case, it can also be perceived negatively because potentially negative consequences with respect to the project are not limited to the current project, but can also extend into future projects. If, for example, a decking has been built with a certain design that has been judged to have an acceptable level of safety, it will take a lot for the same design to be considered unacceptable in future constructions. This applies even if the conditions surrounding the decking are different than in the previous projects.

The existence of project risks of the type described here and also precedent risk is not unique to decking projects. Such have been described in studies of several previous infrastructure projects. For example, [7] shows in a study of six major tunnel projects in Sweden (e.g. Hallandsås tunnel and City tunnel) the existence of similar risks . But, as pointed out above, in projects with deckings the uncertainties can be greater and the risk assessment more complex.

The management of risk takes place above all through design solutions

Many risks related to the transport of dangerous goods under a decking are similar to those encountered in a normal tunnel. In these cases, the safety solutions used are basically the same as those used in tunnels, e.g. fans for fire gases, alarms, escape routes, etc. But when it comes to the risk of large explosions and the possibility of such an impact on buildings above a decking, there is a difference. In a normal tunnel this is not normally a problem, but in a decking project it is a type of risk that must be managed more actively. The most common way to handle it is via different construction solutions. It may seem obvious that this is so, but an alternative to dealing with this type of risk could be restrictions on what can be transported under a decking. However, enforcing restrictions does not seem to be very common on major roads already pointed out as dangerous goods routes.

That this type of risk is managed via construction solutions means that some type of dimensioning load is established, often expressed in the form of the amount of explosive material (tons of TNT) that is assumed to detonate under the cover. With the help of this load, one can then carry out calculations of how the construction would be affected in the event of an explosion under the decking. If the damage caused by such dimensioning loads is judged to be acceptable, the risk is judged to be acceptable.

A problem when using dimensioning scenarios when designing a decking is that you have to decide how large the dimensioning load should be. If no restrictions are imposed on the amount of explosive material that may be transported under the cover, it is conceivable that 80 tons of explosive material is transported there if the transport takes place by rail and 16 tons if it is transported by road. Dimensioning a construction to withstand such powerful explosions without damage to any buildings above is not possible in practice. A difficult question then becomes which load level to start from when carrying out your dimensioning. This choice indirectly means that you decide what is acceptable residual risk in the current case. More severe dimensioning load means lower residual risk, but at the same time higher construction costs. There are no fixed guidelines that describe which dimensioning blast loads to use and thus in practice this becomes something that you have to decide on in connection with individual projects. Guidance on how a decision-maker should proceed to make such a decision is missing according to above.

Large uncertainties create problems

A circumstance that makes the choice of dimensioning explosion scenario difficult is the large uncertainties that exist regarding possible future explosions under a decking. It is very difficult to make estimates of how often such events can conceivably occur and it is also very difficult to assess the extent of damage that will possibly occur, given such an explosion. This type of uncertainty affects the management of risk in many different ways. It contributes, for example, to the difficulty of choosing the dimensioning explosion load (see above). The more likely the catastrophic explosion scenarios are judged to be, the stronger the dimensioning explosion load is justified.

The uncertainty regarding possible future explosions cannot be completely eliminated when a decking is built. It can certainly be reduced significantly, for example by restricting what can be transported. But even so, it is not possible to know with certainty whether the coverage will be affected by a catastrophic scenario in the future. In the context of risk management, two types of uncertainty are usually distinguished: stochastic uncertainty and knowledge uncertainty. Knowledge uncertainty (epistemic) can be reduced by gaining more knowledge about the current risk, but stochastic uncertainty cannot be reduced in that way. The stochastic uncertainty corresponds in this case to the uncertainty of whether one or more explosions will occur in the future and what the consequences will be in that case. In this case, the uncertainty of knowledge corresponds to how likely it is that one or more events will occur, and how likely it is that the consequences in that case will have a certain extent. Regardless of how much knowledge we obtain, we will never be able to know with certainty whether an explosion will occur in the future (stochastic uncertainty). However, through systematic knowledge development, for example by improving the models used to assess the consequences of an explosion, knowledge uncertainty can be reduced.

Knowledge uncertainties can thus be said to exist both in terms of how likely it is that one (or more) explosions will occur in the future, and in terms of how likely it is that the consequences will be of a certain order of magnitude given that a certain explosion scenario has occurred. Knowledge uncertainty of the last type is handled with the help of the designers who are knowledgeable about the impact of explosions on building structures. The knowledge uncertainty of the first type, i.e. how likely it is that a certain type of explosion scenario occurs requires knowledge of how much dangerous goods (which have the potential to cause explosions) are transported under the deck, how often it happens, how often explosions of this type have occurred, etc. Also, explosions in connection with the transport of dangerous goods that occurred in places other than under deckings, including in tunnels, are of interest in being able to reduce knowledge uncertainties. It does not appear that this type of information is widely available, which makes it difficult to assess risk.

Even such a thing as knowledge concerning how much dangerous goods is transported on a certain route in Sweden seems to be difficult to obtain. At least when it comes to details regarding the substances that have the potential to cause large explosions. This is something that was also observed in one of the studies summarized in the literature review [c], but in that case the problem concerned the Netherlands. The fact that it is difficult to know details about dangerous goods transport today, makes it also more difficult to assess what and in what way transport can be planned to take place in the future.

Many actors - Difficult to take an overall perspective

Another important aspect that emerged during the interviews and which was also noted in the Netherlands is the difficulties that arise when a risk management problem involves several actors who have different interests. Having different interests is nothing strange, but what can make things complicated in the context of risk management is when risk management requires trade-offs between different goals and these goals affect the actors in different ways. For example, it is natural that a developer would like to build as much as possible above a decking, that the Swedish Transport Administration wants to have as few restrictions on transport as possible, and that the decking must be built at as low a cost as possible. In practice, trade-offs between such goals are required, and since different actors can value one and the same goal differently, the risk of deadlocks increases. That such balances must take place when the guidance on how to handle them is missing or deficient (see above), and when the uncertainties are very large (see above) can make it difficult to assess different design alternatives and security solutions from an overall perspective. This can lead to blockages in the process which means that it is difficult to move forward. Such have been described previously in Sweden [7] and also in the Netherlands. Finally, not only do the difficulties of adopting a holistic perspective lead to potential deadlocks, they can also lead to a situation of different security solutions, and even different levels of security, in different places in the country.

CONCLUSIONS

In summary, we can state that there is some research concerning tunnels in general and the transport of dangerous goods. Regarding the specific focus on deckings, there are only a few studies that are relatively old, i.e. published before 2010 (the exception is [q]). There are some ideas on how quantitative risk analysis methodology (QRA) can be used to analyze risk with regard to the transport of dangerous goods in connection with deckings and underpasses. The focus is on the Netherlands, where traditional risk measures such as individual risk and UN curves are used to assess risk.

In the other articles, when it comes to specific problems with deckings, underpasses and overbuildings, there is a lack of studies. In some cases, the challenges of deckings are mentioned, but there are no articles dealing with how this type of problem is solved in other countries, or about suggestions on how to manage risks in connection with deckings. There may be several different reasons why the knowledge base in the international research literature is so thin with regard to covers and dangerous goods. The results indicate a lack of academic interest. For example, it could be because cover projects are considered like any other tunnel project and that no particular importance is attached to the fact that there may be buildings over the cover/tunnel. This is probably a perfectly reasonable conclusion regarding the vast majority of types of dangerous goods. However, in cases where the dangerous goods in the tunnel could cause a large-scale explosion/ detonation, the situation could be very different when comparing a normal tunnel with a decking or underpass. In the literature we reviewed, however, we do not find much that deals with this potential problem, except for [n, o, p, q]. And it also doesn't seem that those risk analysis methods (with respect to dangerous goods) in tunnels consider this type of scenario (explosion scenarios with flammable liquids/gases and also BLEVE are considered).

The concept of deckings carries many benefits. At the same time, it could be an initiative challenging the Sendai agreement, since an accident can potentially effect very many people at the same time. The knowledge base whether this is a god idea or not is weak in the scientific literature. The knowledge base is also weak regarding how to assess such risks. From a resilience-base perspective this indicates that such risks are troublesome to consider acceptable. To apply a risk-informed perspective challenges arises on how to determine preferences for very large accidents and uncertainties quite difficult to reduce. Several practical implications have been found in the risk management situations related to deckings that need to be dissolved to make it possible to operationalise effective risk reducing measures. From a risk governance perspective significant effort is necessary to facilitate sound and robust prerequisites to risk management of deckings to safe-guard that we are not drifting into failure and introduce risks in our modern society that we will regret tomorrow. Pushing boundaries is necessary for innovation. It is not contradicting to sustainable development. It is rather a question of how we do it and if we aspire to make risk informed decision or if the decision making is limited to other aspects. Given the circumstances one can also question if it is sensible from national authorities to delegate decision making of this type to single construction projects before more support is offered.

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